

# Congestion Control Methods and Design Guidelines in Wireless Sensor Network

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**Abstract**—A Wireless Sensor Network (WSN) is a collection of sensor nodes that are spatially distributed and organized into a cooperative network to monitor physical or environmental conditions. When an event occurs the sensor node becomes active in transmitting information because of this data traffic increases and might lead to congestion that results in packet drops and decrease network performance. This paper review various existing works used for detecting and controlling congestion.

**Keywords**- Traffic Control; Congestion Control; Cluster Based Approach

## I. INTRODUCTION

Wireless Sensor Network consists of one or more sinks large number of sensor nodes scattered in an area. The downstream traffic from the sink to the sensor nodes usually is a one-to-many multicast. The upstream traffic from sensor nodes to the sink is a many - to- one communication. Due to the focused nature of upstream traffic, congestion more probably appears in the upstream direction. Congestion control is achieved by distributing the network bandwidth across multiple end -to- end connections.

Network congestion happens when offered traffic load exceeds available capacity at any point in a network. In wireless sensor networks, congestion causes overall channel quality to degrade and loss rates to rise, result in buffer drops and increased delays (as in wired networks), and tends to be grossly unfair toward nodes whose information needs to traverse a larger number of radio hops.

Two types of congestion could occur in WSNs they are node-level congestion and link-level congestion. The node-level congestion that is common in conventional networks. It is caused by buffer overflowing in the node and can result in packet loss, and enhanced queuing delay.

Two general approaches to control congestion they are network resource management and traffic control. Network resource management tries to extend network resource to mitigate congestion when it occurs. In wireless network, power control and multiple radio interfaces can be used to increase bandwidth and weaken congestion. This approach, it is necessary to guarantee precise and exact

network resource adjustment in order to avoid over- provided resource or under-provided resource.

There are two general methods for traffic control in WSNs:

- a. *The end-to-end control*: The end-to-end control can impose exact rate adjustment at each source node and simplify the design at intermediate nodes, it results in slow response and relies highly on the round-trip time (RTT)
- b. *The hop-by-hop congestion control*: The hop-by-hop congestion control has faster response. It is usually difficult to adjust the packet-forwarding rate at intermediate nodes mainly because packet forwarding rate is dependent on MAC protocol and could be variable. [3]

Prior work in the sensor networks literature has checked out at two qualitatively different problems: *congestion mitigation*, and *congestion control*. Broadly speaking, mitigation tries to solve the following problem. Consider a sensor network in which each sensor is tasked to periodically transmit samples at some fixed rate. When the aggregate sensor traffic exceeds network capacity, how should nodes *regulate* their transmissions such that the network good put and fairness *degrade* gracefully (rather than exhibit congestion collapse at a point close to network capacity). This is qualitatively different from congestion control, which seeks to *find* an optimal fair rate allocation to sensor nodes that is also maximally *efficient* (so that, when nodes send at this rate, the network is fully utilized, and the per node throughput is close to the sending rate).

Network congestion, which is quite common in wireless networks, occurs when offered load exceeds available capacity or the link bandwidth is reduced due to fading

channels. Network congestion causes channel quality to degrade and loss rates rise. It leads to packets drops at the buffers, increased delays, wasted energy, and requires retransmissions. Moreover, traffic flow will be unfair for nodes whose data has to traverse a significant number of hops. This considerably reduces the performance and lifetime of the network. Additionally, wireless sensor networks (WSN) have constraints imposed on energy, memory and information measures.

Therefore, energy efficient data transmission protocols are required to mitigate congestion resulting from fading channels and excess load. In particular, a congestion control mechanism is needed in order to balance the load, to prevent packet drops, and to avoid network deadlock.

### **Sources and Causes of Congestion**

A Wireless Sensor Network consists of tens or thousands of sensor nodes scattered in an area with one or more sinks. As the data traffic generated by such nodes grows, the offered load exceeds available capacity and the network becomes congested. The main sources of congestion include buffer overflow, channel contention, interference, packet collisions and many-to-one nature. Buffer overflow occurs when the number of incoming packets is greater than the available buffer space. Contention occurs between different flows and different packets of a flow. Interference is caused by simultaneous transmissions along multiple paths within physical proximity of each other. Packet collisions indicate lower level congestion and leads to packet drops. The many-to-one nature of event communication between multiple sources and sink causes bottleneck around sink. Therefore network congestion causes channel quality to degrade, loss rate raises and leads to packet drops at buffers, increased delays and requires retransmissions. Congestion is detrimental to sensor networks because it lowers the throughput called fidelity. It also causes waste of communication resources, waste of energy, and hampers event detection reliability at the sink.

## **II. TECHNIQUES FOR CONGESTION CONTROL**

Congestion control is a method used for monitoring the process of regulating the total amount of data entering the network to keep traffic levels at an acceptable value. It concerns controlling traffic entry into a network, so as to avoid congestive collapse by attempting to avoid oversubscription of any of the processing or link capabilities of the intermediate nodes and networks and taking resource reducing steps, such as reducing the rate of sending packets. Congestion control has to consider network capacity and

application requirements. A number of schemes were proposed to address these challenges:

### **A. Local Cross Layer Congestion Control**

This method [2] is based on buffer occupancy. Input to buffer is of two types: a) Generated packets and b) Relay packets. A sensor node has 2 duties a) Source duty and b) Router duty. During source duty, the sensing unit of the node senses the event and generates packets to be transmitted. A node as a part of router duty receives packets from its neighbors to be forwarded to sink. It has two measures:

- a) It explicitly controls the rate of generated packets in source duty.
- b) It regulates the congestion in router duty based on current load on node.

### **B. Adaptive Duty Cycle based Congestion Control**

Adaptive Duty Cycle based Congestion Control (ADCC) [2] is energy efficient and lightweight congestion control scheme, with duty cycle adjustment for wireless sensor networks. It uses combined mechanism of resource control scheme and traffic control scheme. ADCC periodically calculates the required service time using incoming packet information of child nodes and infers there is congestion or not based on calculated service time. If the congestion degree is below a certain threshold, this scheme adjusts its own duty cycle to reduce congestion. On the other hand if the congestion degree is above threshold, it notifies child nodes of congestion so that transmission rates of child nodes can be adjusted.

### **C. Receiver Assisted Congestion Control**

In Receiver Assisted Congestion Control (RACC) method [3] sender performs loss based control and receiver performs delay based control. Receiver maintains 2 timers, one for recording the packet interarrival time and other for measuring RTT. Sender uses this information from receiver to adjust the congestion window. The receiver can estimate the rate the sender should adapt to make best use of measured bandwidth based on packet interarrival timer. The RTT timer at receiver times the arrival of the next packet and detect packet drop if timeout occurs. Since receiver detects packet drop earlier than sender, it can send ACK to inform sender thereby reducing the waiting time of sender to retransmit a lost packet.

### **D. CAF: Congestion Avoidance and Fairness.**

CAF [6] is a congestion avoidance algorithm which uses the topology information to control congestion. It detects congestion based on the buffer occupancy. In CAF every node calculates its *Characteristic Ratio (CR)*, which is

defined as the ratio of the number of downstream nodes to the number of upstream node. If the CR value is less than one that means there are more upstream nodes than downstream nodes. It uses this information to adjust the rate of its upstream nodes by sending the congestion notification.

#### E. LWBM: Light Weight Buffer Management

LWBM [8] strives to avoid explicit rate signaling between the sensors. In LWBM, every node piggybacks its buffer status to the neighbor nodes. This way, the buffer status of all the nodes is propagated to their neighbor. A node will send data only when the buffer of the receiver node is not full. This way, it adapts the forwarding rate of sensor nodes to near-optimal without causing congestion. It gives how to implement buffer based congestion in different MAC schemes particularly in CSMA with implicit ACK.

### III. DESIGN GUIDELINES FOR CONGESTION CONTROL IN WIRELESS SENSOR NETWORK

An effective congestion control scheme contains three major functions: *Congestion Detection*, *Congestion Notification* and *Rate Adjustment* [1].

**A. Congestion Detection:** In order to control congestion, first we have to find the place which is congested. In traditional networks congestion is detected using end-to-end timeout mechanism or by redundant acknowledgement. In WSNs, to detect the congestion more proactive mechanism like buffer occupancy, channel load and packet service time can be used.

**B. Congestion Notification:** Once congestion has been detected the sensor node has to propagate that information to the sink or to the upstream neighbor of the node. The information can be a single bit or it can be rich information like allowable data rate and congestion degree etc. Another issue is how to send the congestion notification. There are two ways of doing this:

1. *Implicit congestion notification*
2. *Explicit congestion notification.*

In implicit congestion notification, congestion information is piggybacked in the packet header so no need to send a separate control packet. In explicit congestion notification a separate control packet is sent to notify the source.

**C. Rate Adjustment :** After receiving congestion notification, source will adjust its sending rate. The new sending rate depends on the type of information provided in congestion notification. For example if single CN bit is set, AIMD

(Additive Increase Multiple decrease) scheme or its variant can be used or if more information is provided the source can adjust its rate to some exact value.

Massive and random placement of sensor nodes on a monitored field renders node communication a difficult task to be achieved. Interference, congestion, and routing problems are possible to arise at any point in such networks. Routing challenges in WSNs stem from the unique characteristics of these networks, such as limited energy supply, limited computing power, and limited bandwidth on the wireless links, which impose severe restrictions on the design of efficient routing protocols. A number of routing challenges and design issues like, among others, node placement and energy consumption, can affect routing process in WSNs.

Thus, topology control, in conjunction with routing challenges, becomes an important issue that has to be carefully considered in order to achieve proper network operation. Generally, congestion control algorithms in WSNs employ two methods in order to control and avoid congestion. The first method is called traffic control and the second resource control. Algorithms that employ the traffic control method, adjust the rate with which sources inject traffic to the network in order to control congestion. On the other hand, resource control algorithms, employ redundant nodes, which are not in the initial path from source to sink, in the process of forwarding data. Thus, algorithms that employ this method do not control the data rate of the sources but the paths through which the data flows. Different node placements create a variable number of paths which are important for the proper operation of these algorithms.

Placement of nodes in Wireless Sensor Network (WSNs) is often massive and random. Permitting all nodes to transmit concurrently without any control will result in high interference, high energy consumption, and reduced network lifetime. Topology control algorithms focus in lowering the initial network topology, by reducing active nodes and links, thus saving resources and increasing network lifetime. Employing tree structures as topology control algorithms in WSNs has been widely adopted, since it is an efficient and robust solution. The overwhelming majority of algorithms in WSNs construct shared, core-based trees, with the sink as a root. On the other hand, trees that initiate from each source, called source-based trees, are avoided, since each source must create its own routing tree, a fact that creates significant overhead to the network.

### IV. CLUSTER BASED APPROACH TO DEAL WITH CONGESTION

*Coping with the Presence of Interference Coupled Paths.*

In event-based sensor environments such as the one under consideration, the number of distributed sensors is relatively large, while the number of aggregating sinks is likely to be small. This leads to a funnelling effect wherein data flows from different sensor-detected events converge when they reach the proximity of the sink. The flows are likely to follow paths that are largely interference-coupled. The interference coupling between paths becomes pronounced in regions close to the sinks. Typical routing protocols build hop-by-hop paths to the sink and the sources are unaware of the existence of other flows in the network.

One might attempt to perform congestion aware routing. In, sensors avoid overloading congested areas by redirecting traffic away from hotspots. However, in disaster rescue missions, congestion can vary dynamically and there is overhead in reconstructing the routes and maintaining state information at each node. The problems are further exacerbated in the presence of flows belonging to multiple classes, since information regarding high importance events may get lost during congestion. Furthermore, it may be impossible to bypass congested areas that are close to the sink. In the presence of such interfering flows, our objective is, then, to give preference to and maximize the throughput of flows of higher importance.

*The Need for Proactive Rate Control:* In disaster recovery missions, events are likely to be detected at random times and at random places in the sensor network. This dynamically changes the interference patterns among flows and hinders our ability to predict network behavior and effectively identify points of congestion. In addition, the presence of multiple classes of traffic makes the problem even more difficult. One might use reactive techniques to coerce the sources to reduce their rates (especially sources that inject traffic of lower importance) upon congestion.

However, in such cases congestion has already occurred and, thus, reactivity does not avoid critical packet losses. Our goal is to *proactively* monitor the network and identify or predict the onset of congestion. A lightweight control scheme is also required for the information to be quickly exchanged

between clusters to notify the sources that route packets through the congested area to reduce their sending rates.

*The Need for Cluster-Based Traffic Intensity Estimation:* Given that we need an efficient, proactive rate control scheme, it is essential to define a simple, yet effective, congestion detection mechanism which will consider the existence of multiple types of flows. Towards the detection of congestion we then need a methodology for performing traffic intensity estimation.

Such an estimation technique must be simple, decentralized, and lightweight and should be implemented efficiently within the sensors' *localized* scope. Furthermore, in order to reduce the traffic load without having to discard packets, it will be necessary to adjust the rate of the sources themselves. Therefore, the traffic intensity estimates must be propagated to the event sources, which may not be known a-priori. One possibility is that this intensity metric be communicated to all sensors by means of network control packets. However, this would be energy intensive and will unnecessarily increase the network traffic and, thus, will further contribute to congestion.

## V. COMPARISON OF VARIOUS CONGESTION CONTROL TECHNIQUES

The various congestion control techniques that are reviewed follow different strategies for controlling congestion and have different performance measures. Based upon that, the techniques used for controlling congestion, how the congestion is identified, which node is responsible for taking initiative action to control congestion and what is the mechanism used for controlling congestion are compared in this section.

## VI. CONCLUSION

In this paper we have presented techniques congestion control which minimize congestion in the network and various guidelines for congestion control in wireless sensor network. These techniques have made significant effort to tackle the problem of congestion in wireless sensor networks from different aspects and in different situations

| Protocols   | Congestion Detection                            | Congestion Notification | Congestion Avoidance                                    | Energy Efficiency | Bandwidth allocation |
|-------------|-------------------------------------------------|-------------------------|---------------------------------------------------------|-------------------|----------------------|
| STCP [7]    | Queue Length                                    | Implicit                | End-to-End rate adjustment                              | Yes               | Fair                 |
| CODA [8]    | Buffer Occupancy & Channel Load                 | Hop-by-Hop backpressure | End-to-End rate adjustment                              | Yes               | Fair                 |
| CCF [9]     | Packet Service Time                             | Implicit                | Exact hop-by-hop rate adjustment                        | Yes               | Fair                 |
| PCCP [10]   | Packet inter-arrival time & Packet service time | Implicit                | Priority based rate adjustment                          | Yes               | Priority Based       |
| TARA [11]   | Buffer Occupancy & Channel load                 | Implicit                | Dynamically enabling backup nodes                       | No                | -                    |
| Fusion [12] | Queue Length and channel sampling               | Implicit                | Hop-by-Hop flow control, rate limiting, Prioritized MAC | No                | Priority based       |

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